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THEORETICAL CORROBORATION OF THE SELECTION CRITERIA OF THE BREAKING-IN AND SHAPE-COPY GEAR TEETH GRINDING METHODS

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ABSTRACT

Peripheral grinding and disk grinding are commonly applied (without any theoretical justification) for the purpose of flat circular grinding and sharpening of cutting tools, respectively. In this work, the effectiveness of a profile face grinding method of gear teeth using modular grinding-wheels over the breaking-in grinding method was theoretically validated. Moreover, it was found that the cutting zone temperature during face grinding is much lower than compared to that of peripheral grinding, which was attributed to a larger grinding wheel to work piece contact length. Analysis performed in this work showed that the grinding zone temperature appears to be affected by power consumption and a grinding depth, indicating the possibility of lowering the grinding zone temperature by reducing these parameters.

KEYWORDS: Grinding, Burn Mark, Grinding Zone Temperature & Face Grinding

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Original Article

1. INTRODUCTION

Grinding is a process where material is removed through abrasive particles that are contained in a bonded grinding wheel, rotating at a high surface speed. A standard grinding wheel classification system is used to designate abrasive type, grit size, grade, structure, and bond material. Additional identifications are provided through grinding wheel manufacturers. Grinding is characterized by high temperatures and high friction, and most of the energy remains in the ground surface, resulting in high surface temperatures for the work piece [1-2]

2. PROBLEM STATEMENT

Selecting an effective grinding method for face or peripheral grinding is always important during the grinding process development. As a rule of thumb, circular and flat grinding is used for peripheral grinding and sharpening tools are used for face grinding, without any theoretical substantiation in scientific literature [3-5]. For example, literature provides contradictory information regarding the conditions required for decreasing grinding temperature, which is by its turn a very important aspect in the effective application of the two aforementioned grinding methods.

The purpose of work discussed here is to theoretically determine conditions affecting the efficiency of breaking-in and shape copy grinding methods based upon the resulting temperature of the work piece.

3. THEORETICAL MODEL DEVELOPMENT

The most important treatment parameter is the grinding temperature (ΔT). It is defined as follows [6, 7]:

$$T = \frac{l_2 \cdot q}{\lambda} \tag{1}$$

$$l_1 = \sqrt{\frac{2 \cdot \lambda \cdot \tau}{c \cdot \rho}} \tag{2}$$

$$\tau = l / V_d \tag{3}$$

Where l_1 is heat penetration depth in the surface of the work piece (m), c is the specific heat of the material, (J/kg · K), ρ is the density of the material (kg/m^3); τ is contact time for a fixed work piece section with the disc (s), V_d is the speed (m/s), l is the contact length of a disc with the work piece (m), λ is the thermal conductivity of the work piece material (W/m·K), and q is the heat flux density (W/m^2):

$$q = N / S \tag{4}$$

Where N = P_z. V_{disc} is the power of the heating source (W), S is the contact area of disc (S = $b.\ l$) on the work piece (m^2), b is the grinding width (m), $P_z = \sigma.Q/V_{disc}$ is the tangential component of a cutting force (N), σ is the conventional cutting stress (processing power consumption) (N/m^2), V_{disc} is disc speed (m/s), $Q = b.\ t.\ V_d$ is the processing capacity (m^3/s), and t is the grinding depth (m).

After the substitution of the above-mentioned parameters, the heat flux density (q) can be expressed as follows:

$$q = \frac{P_z \cdot V_{disc}}{b \cdot l} = \frac{\sigma \cdot Q \cdot V_{disc}}{V_{disc} \cdot b \cdot l} = \frac{\sigma \cdot t \cdot b \cdot V_d \cdot V_{disc}}{V_{disc} \cdot b \cdot V_d \cdot \tau}. \tag{5}$$

$$q = \frac{\sigma \cdot t}{\tau} \tag{6}$$

It can be seen that q is reduced with increased treatment time (τ) and (taking equation 2 into consideration) heat penetration dept (l_1) parameter. Also τ affects q with a greater scale compared to l_1. As a result, grinding temperature (T) will be reduced by increasing of treatment time:

$$T = \sigma.t.\sqrt{\frac{2}{c.\rho.\lambda}}.\frac{1}{\tau} = \sigma \cdot t \cdot \sqrt{\frac{2}{c \cdot \rho \cdot \lambda} \cdot \frac{V_d}{l}}\ . \tag{7}$$

According to equation 7, the bigger the l length of a circle and work piece contact l, the lower is grinding temperature T. From this point of view, it is obvious that the face grinding is a preferred treatment method due to the bigger disc and work piece contact length l. In this regard, the value l for peripheral grinding was determined according to the diagram of grinding parameters shown in Figure 1.

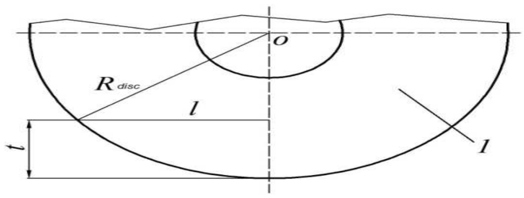

Figure 1: The Grinding Parameters for Disc 1

$$l = \sqrt{R_{disc}^2 - (R_{disc} - t)^2} = \sqrt{R_{disc}^2 - R_{disc}^2 + 2 \cdot R_{disc} \cdot t - t^2},$$

Where, R_{disc} is a disc radius (m)

Here, grinding depth t^2 is negligible compared with the grinding disc radius so it can be neglected, therefore we obtain:

$$l = \sqrt{2 \cdot R_{disc} \cdot t} \tag{8}$$

Similarly, the *l* value can be determined for face grinding considering the width of the disc working part B instead of the grinding depth *t*:

$$l = 2 \cdot \sqrt{2 \cdot R_{disc} \cdot B} \cdot \tag{9}$$

After the substitution of equations 8 and 9 in equation 7, a formula for determining the temperature during flat face grinding is obtained:

$$T = \sigma \cdot t \cdot \sqrt{\frac{1}{c \cdot p \cdot \lambda} \cdot \frac{V_d}{\sqrt{2 \cdot R_{disc} \cdot B}}} \tag{10}$$

And for peripheral grinding method:

$$T = \sigma \cdot t \cdot \sqrt{\frac{2}{c \cdot p \cdot \lambda} \cdot \frac{V_d}{\sqrt{2 \cdot R_{disc} \cdot t}}} \tag{11}$$

According to equations 10 and 11, it can be deduced that temperature is always lower in case of face grinding compared to peripheral grinding because B>> *t*. As illustrated above, this behavior is attributed to the increased length of the disc and the work piece contact. Further analysis shows that σ and t had a great impact on the temperature, thus further reduction in temperature can be obtained by lowering their values. However, it is known that decreasing grinding depth t decreases the treatment capacity ($Q = b.\ t.\ V_d$). Therefore, to insure the reduction in temperature (*T*) in face grinding without reducing the treatment capacity (*Q*), equation 6 need to be expressed as follows:

$$T = \sigma \cdot \sqrt{\frac{1}{c \cdot p \cdot \lambda} \cdot \frac{Q \cdot t}{b \cdot \sqrt{2 \cdot R_{disc} \cdot B}}} \tag{12}$$

In this case, while ensuring a predetermined treatment capacity *Q*, grinding depth t reduction helps to decrease the temperature *T*. Therefore, the effective use of multiple-pass face grinding method requires increasing the speed of detail according to the law $V_d = Q/\ (b.t)$. This may explain, for example, that the effective gear grinding operation using breaking-in method has to be performed with more effective multiple-pass grinding. To implement the method of creep-feed grinding with stock removal while performing one or more drivages, according to the law (6), it is necessary to reduce the conventional cutting stress (energy consumption of treatment) *σ*.

In this case, even a small reduction of the σ stress will allow to significantly increase the grinding depth and possibly to increase the treatment capacity *Q*. Consequently, using grinding discs which have an improved cutter power allows to shift from multiple-pass grinding to the more efficient deep grinding method, and thus to implement the teeth grinding shape copy method. The treatment effect in this case will be also achieved due to the fact that a significant decrease in the number of disc drives reduces auxiliary time, and this is extremely important for gear grinding treatment, which is characterized by high labor intensity.

It should be noticed that the shape copy method in case of teeth grinding process requires face grinding treatment using profiled (conical) disc. Therefore, in this case the law (12) is fair.

This decision can also be reached using a different approach, considering the law (6). Obviously, increasing the contact time τ of the fixed work piece section with the disc with contact length l allows the grinding depth t to be increased alongside with the significant decreasing of detail speed V_d. In fact, it involves the implementation of a high-capable deep grinding, while ensuring a relatively low grinding temperature T which allows for eliminating the formation of the burn marks on the treated surfaces. Figure 2 shows two methods of the gear teeth grinding.

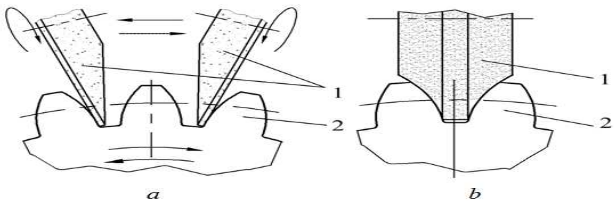

Figure 2: Teeth Grinding Using (a) Breaking-in and (b) Shape Copy Methods; 1 - Grinding Disc; 2 - Treated Teeth

In order to assess the implementing potential of these teeth grinding methods, experimental studies of basic treatment parameters were conducted using the HOFLER RAPID 1250 model with the special highly porous profiled disc, which has a high cutting capacity in terms of effective deep grinding. Processing was carried out with a disc velocity of 35 m/s, the grinding depth of 0.15 - 0.2 mm, and the detail speed (along the treating gear tooth) up to 6 m/min.

4. CONCLUSIONS

Thus, the stock removal of 0.4 mm per side was made during the 2-3 disc drives. Compared with the conventional breaking-in grinding method, this method allowed increasing effectiveness up to 5 times. Also the treated surfaces had no burnt marks and other temperature defects, which indicates a relatively low temperature and high disc cutting power during a creep-feed grinding

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